

15/10/14

## Description

## Casting Nozzle

## &lt;Technical Field&gt;

5           The present invention relates to a casting nozzle mainly concerning a nozzle for continuously casting steel, such as an immersion nozzle, a long nozzle, etc.

## &lt;Background Art&gt;

10           An immersion nozzle, a long nozzle, a tundish nozzle, a semi-immersion nozzle, etc. are known as nozzles for continuously casting steel.

          An "immersion nozzle" will be described as an example of the nozzle for continuously casting steel. The purpose of use of the immersion nozzle is to seal a tundish and a mold from each other to thereby prevent re-oxidation of molten steel and to control a flow of molten steel out of a discharge hole of the immersion nozzle and uniformly supply molten steel into the mold to attain operating stability and improvement in cast  
15           piece quality.

          As a method for controlling the flow rate of molten steel for supplying the molten steel into the mold through the immersion nozzle, there is known a stopper method or a slide plate method. Particularly, in the slide plate method, a set  
20           of two or three hole-including plates are used so that one of  
25

the hole-including plates is slid to adjust the flow rate on the basis of the aperture of the hole. Accordingly, if the aperture is small, a drift is apt to occur in the immersion nozzle. If such a drift occurs in the immersion nozzle, the flow rate out of each discharge hole becomes so ununiform that a drift occurs in the mold to deteriorate cast piece quality.

Prevention of the drift in the immersion nozzle is important in order to improve cast piece quality. As a technique for preventing the drift in the immersion nozzle, there is known a method of improving the shape of an inner hole portion of the nozzle. For example, "provision of ring-like protrusions" has been proposed as described in an "immersion nozzle (Patent Document 1) having a molten steel flow hole provided with a plurality of step portions", an "immersion nozzle (Patent Document 2) having a molten metal introduction portion provided with a throttle portion to use a region of from the throttle portion to a discharge hole as a flow rate relaxing portion", and a "continuous casting immersion nozzle (Patent Document 3) having four or more wavy folds each shaped like a circular arc and provided continuously in the flowing direction of molten metal in an inner surface of a nozzle hole so that the distance between adjacent peaks of the folds is from 4 to 25 cm and the depth between a peak and a corresponding trough is from 0.3 to 2 cm". "Provision of helical protrusions" has been also proposed as described in a "casting nozzle (Patent Document

4) having an inner wall provided with spiral grooves or protrusions", an "immersion nozzle (Patent Document 5) having an inner wall preferably provided with double-helical or triple-helical protrusions", and so on. There have been  
5 further proposed a "nozzle (Patent Document 6) having semi-spherical concave-convex portions formed in a surface of a molten metal flow passage", a "casting nozzle (Patent Document 7) having convex or concave portions in an inner surface of a nozzle hole so that the convex or concave portions are  
10 continuous in a direction perpendicular to the flowing direction of molten steel", and an "immersion pipe (Patent Document 8) having a throttle ring disposed in a free transverse section of the immersion pipe to narrow the free transverse section of the immersion pipe and form a longitudinal section of the  
15 throttle ring to generate a laminar flow of molten metal in an outflow port, the throttle ring being disposed in the immersion pipe".

On the other hand, when Al killed steel or the like is cast, a mainly alumina-containing non-metal inclusion  
20 (hereinafter referred to as "alumina" simply in this description) is generally attached and deposited on a molten steel flow hole portion surface (inner pipe surface) of the immersion nozzle. If the amount of alumina deposited on the inner pipe surface of the immersion nozzle becomes large, the  
25 operation becomes unstable because the increase in the amount

of alumina causes narrowing of the nozzle inner hole portion, reduction in casting speed, drifting of a discharge flow, blocking of the nozzle inner hole, etc. Moreover, if part of the deposited alumina is dropped out by a flow of molten steel, penetrated into the mold and caught in a solidification shell, cast piece quality is lowered because of a large-size inclusion defect. As described above, "deposition of alumina" on the inner pipe surface of the immersion nozzle exerts a bad influence on both operation and cast piece quality as well as reduction in the lifetime of the nozzle. This phenomenon also occurs in other nozzles such as a long nozzle, a tundish nozzle, etc.

As general means for preventing alumina from being deposited in the casting nozzle, there is known a method of spraying inert gas. Generally, this method is a method of spraying inert gas from an insert nozzle or upper plate of a slide gate or from a stopper fitting portion of an insertion type immersion nozzle. When the cleanliness factor of molten steel is low, a method of spraying inert gas directly from the immersion nozzle is also carried out.

A material (alumina-deposition-free material) applied to the nozzle has been proposed in order to prevent alumina from being deposited on the casting nozzle. For example, provision of a boron nitride (BN)-containing material (Patent Document 9), a BN-C refractory material (the aforementioned Patent Document 1), or the like, in the inner hole portion of

the immersion nozzle has been proposed. Provision of an  $\text{Al}_2\text{O}_3\text{-SiO}_2\text{-C}$  material, a  $\text{CaO-ZrO}_2\text{-C}$  material, a carbonless refractory material or the like has been further proposed.

A large number of proposals have been further made from  
5 the aspect of the shape of the inner hole portion of the casting  
nozzle. For example, besides the aforementioned Patent  
Documents 1 to 8, there have been proposed a "molten metal  
injection nozzle (Patent Document 10) having a plurality of  
grooves formed along the lengthwise direction of its inner wall  
10 in a region of the inner wall including a portion of collision  
with molten metal", a "molten metal induction pipe (Patent  
Document 11) having an inner wall provided with at least one  
helical step and having a portion in which the sectional area  
of a molten metal flow path is reduced gradually in a region  
15 ranging from the inlet side to the outlet side", a "continuous  
casting immersion nozzle (Patent Document 12) having a slit-like  
discharge hole in a bottom portion of the continuous casting  
immersion nozzle, and orifices in the inside of the nozzle,  
having a structure in which the shape of a planar section  
20 surrounded by each orifice is elliptical or rectangular or such  
a shape that each rectangular short side replaced by a circular  
arc to narrow a flow of molten metal flowing in the immersion  
nozzle, and formed so that the direction of each long side of  
the planar section surrounded by the orifice is perpendicular  
25 to the direction of each long side of a planar section of the

slit-like discharge hole in the bottom portion", an "immersion nozzle (Patent Document 13 or 14) having a twisted tape-like swirl vane for generating a swirl flow of molten steel in the nozzle and shaped so that the inner diameter of the nozzle is narrowed by a lower portion of the swirl vane", and so on.

[Patent Document 1]: Japanese Utility Model Publication No. 23091/1995 (Claims 1 and 5)

[Patent Document 2]: Japanese Patent No. 3,050,101 (Claim 1)

[Patent Document 3]: Japanese Patent Laid-Open No. 269913/1994 (Claim 1)

[Patent Document 4]: Japanese Patent Laid-Open No. 130745/1982 (Scope of Claim for a Patent)

[Patent Document 5]: Japanese Patent Laid-Open No. 47896/1999 (Claims 1 and 2)

[Patent Document 6]: Japanese Patent Laid-Open No. 89566/1987 (Claim 1 in Scope of Claim for a Patent)

[Patent Document 7]: Japanese Utility Model Publication No. 72361/1986 (Figs. 2 to 4)

[Patent Document 8]: Japanese Patent Laid-Open No. 207568/1987 (Claim 1 in Scope of Claim for a Patent)

[Patent Document 9]: Japanese Utility Model Publication No. 22913/1984 (Scope of Claim for a Utility Model Registration)

[Patent Document 10]: Japanese Patent Laid-Open No. 40670/1988 (Claim 1 in Scope of Claim for a Patent)

[Patent Document 11]: Japanese Patent Laid-Open No.  
41747/1990 (Scope of Claim for a Patent)

[Patent Document 12]: Japanese Patent Laid-Open No.  
285852/1997 (Claim 2)

5 [Patent Document 13]: Japanese Patent Laid-Open No.  
2000-237852 (Claim 1)

[Patent Document 14]: Japanese Patent Laid-Open No.  
2000-237854 (Figs. 1 to 3)

10 In the aforementioned conventional techniques (see  
Patent Documents 1 to 8 and 10 to 14) paying attention to the  
shape of the nozzle inner hole portion, an effect of preventing  
a drift of the molten steel flow can be expected to a certain  
degree because a turbulent flow is partially generated. There  
is however a problem that "deviation in discharge flow rate  
15 distribution of molten steel" occurs easily particularly in  
the discharge hole portion, that is, a minus flow (suction flow)  
occurs or when a plurality of discharge holes are provided,  
imbalance occurs in the flowing amount out of each discharge  
hole.

20 Description will be further made taking the immersion  
nozzle as an example. The nozzle has an important role of  
supplying molten steel into the mold uniformly. Actually, a  
flow of molten steel in the nozzle is provided as a drift because  
of flow rate control based on a slide valve. There is a  
25 possibility that this will cause a drift of molten steel in

the discharge hole and will cause deterioration of cast piece quality because this has influence on the inside of the mold. Besides the flow rate control based on the slide valve, flow rate control based on a stopper and a vortex of molten steel generated in a vessel at the time of discharge of molten steel are causes of occurrence of a drift in the immersion nozzle.

The aforementioned problem can be solved to a certain degree by the shape of the nozzle inner hole portion listed in the conventional techniques. Particularly in the "immersion nozzle having a plurality of step portions" described in the aforementioned Patent Document 1, a drift suppressing effect can be obtained to a certain degree because molten steel passes through the portion where the sectional area of the nozzle is reduced by each step. The height of the step used in practice is about 5 mm. If the height of the step is made higher, the drift suppressing effect can be improved but there is a problem that the amount of passage of molten steel (throughput) is limited by decrease in sectional area of the step portion and increase in frictional resistance of the pipe wall. Also in the "nozzle having semi-spherical concave-convex portions in a surface of a molten metal flow path" described in the aforementioned Patent Document 6, the effect of preventing a drift of molten steel and the effect of suppressing deposition of alumina cannot be always satisfied.

The drift of molten steel in the nozzle inner hole portion



causes a "drift of molten steel in the discharge hole portion". The "drift of molten steel in the discharge hole portion" will be described with reference to (A) and (B) in Fig. 1. A molten steel flow a shown in (A) of Fig. 1 is not uniformly discharged from the discharge hole portion (side hole type) but drifts as represented by the solid-line arrow shown in the drawing. That is, a minus flow (suction flow) is generated. As a result, the possibility that mold powder will be involved as represented by the broken-line arrow occurs and causes deterioration of cast piece quality. Not only in the "side hole type" shown in (A) of Fig. 1 but also in a "bottom hole type" straight immersion nozzle 10b shown in (B) of Fig. 1, the molten steel flow a' does not uniformly flow out of the discharge hole portion (bottom hole type) so that a drift is generated in the discharge hole portion as represented by the solid-line arrow shown in the drawing. Incidentally, (A) and (B) of Fig. 1 are based on the "water model experiment" of inner pipe straight immersion nozzles 10a and 10b having discharge hole portions of a "side hole type" and a "bottom hole type" respectively. This phenomenon occurs even in the case where the shape of the nozzle inner hole portion is changed to any one of shapes listed in the conventional techniques. This fact has been confirmed from the "water model experiment" performed by the present inventors.

There is also a problem that alumina is attached and deposited on a space between protrusions disposed in the molten

steel flow hole portion of the immersion nozzle in accordance with the method of providing the protrusions when Al killed steel or the like is cast. If alumina is deposited so that the space between the protrusions is filled with alumina, the effect based on the provision of the protrusions is eliminated so that the drift preventing effect is spoilt. At the same time, predetermined throughput (the amount of passage of molten steel per unit time) cannot be kept because the effective sectional area of the inner hole portion is reduced. There is a disadvantage that the nozzle cannot operate.

Incidentally, in the method of spraying inert gas which is one of the conventional techniques for preventing alumina from being deposited on the casting nozzle, the alumina deposition preventing effect can be expected but there is a disadvantage that melting loss in the inner surface of the nozzle discharge hole is made severe by the bubbling stirring effect of the inert gas. In addition, there is a problem that cast piece defects occur easily because pinhole defects occur easily based on gas bubbles in accordance with the size, dispersibility, etc. of the bubbles generated. On the other hand, in the alumina-deposition-free material adapted to the nozzle, the alumina deposition preventing effect can be expected to a certain degree but it cannot be said that the required effect is accomplished.

<Disclosure of the Invention>

The present invention is accomplished in consideration of the defects and problems in the background art and an object of the invention is to provide a casting nozzle in which a "drift of molten steel from the inside of the nozzle to a discharge hole portion" caused by flow rate control can be presented and in which alumina can be restrained from being deposited particularly on a space between protrusions of a nozzle inner hole portion.

To achieve the foregoing object, that is, to suppress drifting in the nozzle inner hole portion and prevent deposition of alumina, a casting nozzle according to a first aspect of the invention is a casting nozzle having a molten steel flow hole portion in which a plurality of independent protrusion portions and/or concave portions discontinuous in both directions parallel and perpendicular to a molten steel flowing direction are disposed, the casting nozzle characterized in that each of the protrusion portions and/or concave portions has a size satisfying the following expressions (1) and (2):

$$H \geq 2 \text{ (unit: mm)} \quad \dots \text{ expression (1)}$$

$$L > 2 \times H \text{ (unit: mm)} \quad \dots \text{ expression (2)}$$

[in which "H" shows the maximum height of the protrusion portion or the maximum depth of the concave portion, and "L" shows the maximum length of a base portion of the protrusion portion or concave portion].

According to the casting nozzle according to the first

aspect of the invention, the aforementioned protrusion portions and/or concave portions are disposed to generate a "turbulent flow" for a flow of molten steel in each of the portions to thereby prevent stagnation and drifting of the molten steel flow in the molten steel flow hole portion to make it possible to prevent deposition of alumina and prevent drifting of molten steel particularly in the discharge hole portion. As a result, continuous casting can be performed easily. In addition, high-quality steel can be cast easily without involving of mold powder.

A casting nozzle according to each of second to twelfth aspects of the invention is characterized in that the following constituent requirement is satisfied.

According to a second aspect of the invention, there is provided a casting nozzle defined in the first aspect, characterized in that each of the protrusion portions and/or concave portions satisfies the following expression (3):

$$L \leq \pi D/3 \text{ (unit: mm)} \quad \dots \text{ expression (3)}$$

[in which "L" shows the maximum length of a base portion of the protrusion portion or concave portion, and "D" shows the inner diameter (diameter) of the nozzle before the protrusion portions or concave portions are disposed ( $\pi$ : the ratio of the circumference of a circle to its diameter)].

According to a third aspect of the invention, there is provided a casting nozzle defined in the first or second aspect,

characterized in that the protrusion portions and/or concave portions are disposed so that the inner surface area of a molten steel flow path in a range in which the protrusion portions and/or concave portions are disposed is 102-350 % as large as the inner surface area of the molten steel path before disposition of the protrusion portions and/or concave portions.

According to a fourth aspect of the invention, there is provided a casting nozzle defined in any one of the first to third aspects, characterized in that the casting nozzle has a portion where the protrusion portions and/or concave portions are disposed so zigzag that positions are displaced at least in the direction perpendicular to the molten steel flowing direction.

According to a fifth aspect of the invention, there is provided a casting nozzle defined in any one of the first to fourth aspects, characterized in that the protrusion portions and/or concave portions are disposed in the whole or part of the molten steel flow hole portion of the casting nozzle.

According to a sixth aspect of the invention, there is provided a casting nozzle defined in any one of the first to fifth aspects, characterized in that the protrusion portions and/or concave portions are disposed so as to be not higher than a meniscus of the casting nozzle.

According to a seventh aspect of the invention, there is provided a casting nozzle defined in any one of the first

to sixth aspects, characterized in that the distance between bases of the protrusion portions in a direction parallel to the molten steel flowing direction is not smaller than 20 mm.

According to an eighth aspect of the invention, there  
5 is provided a casting nozzle defined in any one of the first to seventh aspects, characterized in that the height of each of the protrusion portions is 2-20 mm.

According to a ninth aspect of the invention, there is provided a casting nozzle defined in any one of the first to  
10 eighth aspects, characterized in that the number of the protrusion portions disposed in the molten steel flowing hole portion is not smaller than 4.

According to a tenth aspect of the invention, there is provided a casting nozzle defined in any one of the first to  
15 ninth aspects, characterized in that the "angle between a nozzle inner pipe and a lower end portion of each of the protrusion portions" in a direction parallel to the molten steel flowing direction is not larger than 60°.

According to an eleventh aspect of the invention, there  
20 is provided a casting nozzle defined in any one of the first to tenth aspects, characterized in that the protrusion portions are molded so as to be integrated with a body of the casting nozzle.

According to a twelfth aspect of the invention, there  
25 is provided a casting nozzle defined in any one of the first

to eleventh aspects, characterized in that the casting nozzle is an immersion nozzle for continuously casting steel.

<Brief Description of the Drawings>

5            Fig. 1 is a typical view for explaining a drift of molten steel in a discharge hole portion of an immersion nozzle. In Fig. 1, (A) is a typical view of an immersion nozzle (side hole type) having a straight inner pipe, and (B) is a typical view of an immersion nozzle (bottom hole type) having a straight  
10 inner pipe.

Fig. 2 is a view showing Examples 1 to 8 of the invention.

Fig. 3 is a view showing Comparative Examples 1 to 8.

Fig. 4 is a sectional perspective view of an immersion nozzle according to an embodiment (Example 1) of the invention.

15            Fig. 5 is a sectional perspective view of an immersion nozzle according to an embodiment (Example 2) of the invention.

Fig. 6 is a view for explaining points (1) to (9) at which discharge flow rates are measured in a water model experiment apparatus. In Fig. 6, (A) is a sectional view showing a right  
20 lower portion of the apparatus, and (B) is a view showing the shape of an opening in a discharge hole surface  $x$  in (A).

Fig. 7 is a view showing "results of measurement of discharge flow rates" measured at the points (1) to (9) in Fig. 6 in each of immersion nozzles according to Comparative Example  
25 1 and Example 1.

Fig. 8 is a view cut vertically in a direction parallel to the direction of a molten steel flow hole portion and showing an example (Example 9) in which protrusion portions are disposed in the molten steel flow hole portion.

5 Fig. 9 is a view for explaining immersion nozzles according to Example 10 and Comparative Examples 11 and 12. In Fig. 9, (A) is a sectional view cut vertically in parallel to the molten steel flowing direction and showing the immersion nozzle according to Example 10, and (B) and (C) are sectional views  
10 cut vertically in parallel to the molten steel flowing direction and showing the immersion nozzles according to Comparative Examples 11 and 12, respectively. In Fig. 9, (D) is a view showing a section of each protrusion portion taken in parallel to the molten steel flowing direction in the immersion nozzle  
15 (Example 10) depicted in (A), and (E) is a view showing a section of each protrusion portion taken in parallel to the molten steel flowing direction in the immersion nozzle (Comparative Example 12) depicted in (C). In Fig. 9, (D) and (E) are views for explaining results of a "water model experiment" for the  
20 immersion nozzles according to Example 10 and Comparative Example 12.

Fig. 10 is a view showing examples in which protrusion portions are disposed in a molten steel flow hole portion. In Fig. 10, (A) shows an immersion nozzle according to Example  
25 11, and (B) shows an immersion nozzle according to Comparative



Example 13. In Fig. 10, (C) is a view showing a "result of the water model experiment" for Example 11, and (D) is a view showing a "result of the water model experiment" for Comparative Example 13.

5            Fig. 11 is a view showing the "sectional shape (sectional shape cut in parallel to the molten steel flowing direction) of each protrusion portion" disposed in each of immersion nozzles according to Examples 12 to 16 and Comparative Examples 14 to 18 and further showing the "presence or absence of stagnation  
10 just under each protrusion" and "straightening effect".

            Fig. 12 is a view showing results of the "relation between the height (H) of each protrusion and the length (L) of a base portion of the protrusion" examined by a fluid calculation software program in the condition that the length (L) is fixed  
15 to "L = 22 mm". In Fig. 12, (A) is a view showing an example of calculation at H = 7 mm, (B) is a view showing an example of calculation at H = 11 mm, and (C) is a view showing an example of calculation at H = 18 mm.

            Fig. 13 is an expanded view of an inner pipe of a nozzle  
20 in which a plurality of independent protrusions are disposed. In Fig. 13, (A) shows an example in which spherical protrusions are disposed, and (B) shows an example in which elliptical protrusions are disposed.

            Fig. 14 is a view showing places where independent  
25 protrusion portions are disposed. In Fig. 14, (A) shows an

example in which the independent protrusion portions are disposed above a meniscus, (B) shows an example in which the independent protrusion portions are disposed in a range ranging a portion above the meniscus to a portion below the meniscus, (C) shows an example in which the independent protrusion portions are disposed on the whole surface of the molten steel flow hole portion of the nozzle, and (D) shows an example in which the independent protrusion portions are disposed below the meniscus.

#### <Best Mode for Carrying Out the Invention>

A mode of a casting nozzle according to the invention will be described below. Before the description, the casting nozzle according to the invention will be described in more detail inclusive of the technical significance of the aforementioned expressions (1) and (2) specified by the invention.

The reason why the maximum height or maximum depth (H) of the protrusion portion or concave portion is set to satisfy " $H \geq 2$  (mm)" in the expression (1) in the invention is that the aforementioned operation and effect are obtained, that is, a "turbulent flow" is generated for a flow of molten steel particularly in the portion of provision of the protrusion portions and/or concave portions (hereinafter also referred to as "concave-convex portions" simply) to prevent the flow

of molten steel from stagnating or drifting in the molten steel flowhole portion to thereby prevent alumina from being deposited. If the maximum height or maximum depth (H) is smaller than 2 mm, the alumina deposition suppressing effect can be hardly  
5 obtained undesirably because it is difficult to generate the "turbulent flow" for the flow of molten steel in the concave-convex portions and it is difficult to obtain the straightening effect.

The fact that the aforementioned effect can be hardly  
10 obtained when the maximum height or maximum depth (H) of each of the protrusion portions is smaller than 2 mm will be described specifically on the basis of Comparative Example 5 which will be described later. Comparative Example 5 is a nozzle of "H = 1 mm". As shown in Fig. 3 which will be described later (see  
15 the column of Comparative Example 5), drifting of left and right discharge flows was observed in a water model experiment of this nozzle, and a minus flow (suction flow) was observed in a result of flow rate measurement in the discharge hole portion. Also in a test for an actual machine, the amount of alumina  
20 deposited on the inner pipe was as large as "10 mm" (see the column of "Comparative Example 5" in Fig. 3 which will be described later). Accordingly, it was understood that the effect based on provision of the protrusions cannot be observed in the case of "H = 1 mm".

25 The reason why the maximum length (L) of the base portion

is set to satisfy " $L > 2 \times H$  (mm)" in the expression (2) in the invention is that (1) stagnation under the protrusions can be prevented and (2) the protrusions can be prevented from dropping out due to collision with the flow of molten steel.

5 If the maximum length (L) of the base portion is not larger than " $2 \times H$ " mm, it is difficult to obtain the effects (1) and (2) and it is difficult to obtain the "molten steel drift preventing effect", undesirably.

For confirming the "(1) stagnation preventing effect",  
10 Fig. 12 shows a result of examination into the "relation between the height (H) of the protrusion and the length (L) of the base portion of the protrusion" based on a fluid calculation software program. Here is shown an example of calculation in the case where the height (H) of each of the protrusions is changed to  
15 "(A):  $H = 7$  mm, (B):  $H = 11$  mm and (C):  $H = 18$  mm" while the length (L) of the base portion of each of the protrusions is fixed to " $L = 22$  mm". As is obvious from Fig. 12, no stagnation portion can be observed on and under the protrusions in (A) of Fig. 12 satisfying the "expression (2):  $L > 2 \times H$  (mm)" whereas  
20 a stagnation portion 64 can be observed in (B) and (C) of Fig. 12 not satisfying the expression (2). That is, it is guessed that when the relation between the height (H) of the protrusion and the length (L) of the base portion does not satisfy " $L > 2 \times H$ ", the stagnation portion 64 is generated so that alumina  
25 is deposited (attached) thereon at the time of casting in the

actual machine. [Incidentally, in Fig. 12, the reference numeral 61 designates a body (inner pipe side operating surface) of the nozzle; 62, a protrusion portion; and 63, a result of fluid calculation (a flow of molten steel)]. The relation  
5 between the height (H) of the protrusion and the length (L) of the base portion "the expression (2):  $L > 2 \times H$ " will be described more specifically on the basis of Examples and Comparative Examples which will be described later. In each of Comparative Examples 3, 4, 6, 7 and 8 not satisfying the  
10 relation of "the expression (2):  $L > 2 \times H$ ", the amount of an alumina inclusion deposited is "5-7 mm" (see Fig. 3 which will be described later). In each of Examples 1 to 8, there is obtained a good result that the amount is "not larger than 3 mm" (see Fig. 2 which will be described later).

15 The "(2) prevention of the protrusion from dropping out", that is, "strength of the protrusion" will be described specifically on the basis of Examples and Comparative Examples which will be described later. In each of Examples 1 to 8 satisfying the "expression (2):  $L > 2 \times H$ ", damage (dropout)  
20 of the protrusion due to collision with the flow of molten steel was not observed in a product cast by the actual machine (see Fig. 2 which will be described later). On the contrary, in each of Comparative Examples 3, 4, 6 and 7, dropout of the protrusion was observed (see Fig. 3 which will be described  
25 later). Each of Comparative Examples does not satisfy the

"expression (2):  $L > 2 \times H$ ". For keeping the strength of the protrusion, it is important to satisfy " $L > 2 \times H$ ". Incidentally, in Fig. 2 (Examples 1 to 8) and Fig. 3 (Comparative Examples 1 to 8), the relation between the height (H) of the protrusion and the length (L) of the base portion is expressed in " $L/H$ ". For satisfying the "expression (2):  $L > 2 \times H$ " specified by the invention, it is necessary that " $L/H$ " is a value ( $2 <$ ) larger than 2.

In the casting nozzle according to the invention, the shape of each of the protrusion portions and/or concave portions is not particularly limited as long as each of the protrusion portions and/or concave portions has a size satisfying the expressions (1) and (2). Any shape such as a semi-spherical shape, an elliptical shape, an approximately polygonal pyramid shape, etc. may be used or any suitable combination of these shapes may be provided. Incidentally, the term "approximately polygonal pyramid shape" in the invention means a shape formed from three or more line segments and having a top end portion shaped like an acute angle, a flat surface or a curved surface with a ridge shaped like a line or a curve (e.g. see "Shape of Protrusion" in Examples 6 to 8 shown in Fig. 2 which will be described later).

The casting nozzle according to the invention is characterized in that dimensions satisfying the expressions (1) and (2) are provided. As a preferred embodiment thereof,

the maximum length L (mm) of the base portion of each of the concave-convex portions is set to be not larger than 1/3 as large as the length of the circumference of the nozzle with the inner diameter D (mm) before provision of the concave-convex portions, that is, the following expression (3) is satisfied.

$$L \leq \pi D/3 \text{ (unit: mm)} \quad \dots \text{ expression (3)}$$

[in which "L" shows the maximum length of the base portion of each of the protrusion portions or concave portions, and "D" shows the inner diameter (diameter) of the nozzle before provision of the protrusion portions or concave portions ( $\pi$ : the ratio of the circumference of a circle to its diameter)].

The operation and effect of the expression (3) will be described specifically on the basis of Fig. 13. Fig. 13 is an extend elevation of the inner pipe of a nozzle provided with a plurality of independent protrusions. (A) shows an example of provision of spherical protrusions (satisfying the expression (3)). (B) shows an example of provision of elliptical protrusions (not satisfying the expression (3)). A transparent acrylic nozzle was subjected to a water model experiment. As a result, flows represented by the "arrows" in (A) and (B) of Fig. 13 were confirmed.

In the case of (A) of Fig. 13 which shows an example of provision satisfying the "expression (3):  $L \leq \pi D/3$ ", an oblique flow from an adjacent protrusion goes to just under one protrusion so smoothly that no stagnation portion is generated.

On the contrary, in the case of (B) of Fig. 13 which does not satisfy the expression (3), a stagnation portion is generated just under each protrusion because an oblique flow from an adjacent protrusion can hardly reach just under one protrusion.

5           The flow of molten steel falling down collides with each protrusion, so that the direction of the flow changes to thereby generate a local turbulent flow. Originally, the flow of molten steel hardly goes to just under one protrusion physically. Therefore, the presence of a flow of molten steel colliding  
10 with a protrusion adjacent to the protrusion or the presence of a flow induced and inverted by a protrusion obliquely below the protrusion is important. On the contrary to independent protrusions, a nozzle having a conventional stepped structure (see the aforementioned Patent Document 1) will be considered.  
15 The step comes under the category of a ring-like protrusion. Because the flow of molten steel stagnates just under the ring-like protrusion, a stagnation portion is generated. There is a disadvantage that an alumina inclusion is easily deposited on the stagnation portion when the actual machine is used. The  
20 maximum length (L) of the base portion of each of the concave-convex portions must be considered in order to improve this point. The present inventors have found from the result of the water model experiment that it is preferable that the "expression (3):  $L \leq nD/3$ " is satisfied. [Incidentally, in  
25 the case of an oval shape (nozzle having an upper portion shaped



like a general circle, and a lower portion enlarged like an ellipse or an oblong) used in a thin slab continuous casting machine or the like, "D" is set as the maximum inner diameter of an enlarged region of the lower portion of the inner pipe].

5           In accordance with the provision of the concave-convex portions in the molten steel flow hole portion according to the invention, the inner surface area of the molten steel flow path changes compared with the reference structure before the provision. It is preferable that the inner surface area of  
10 the molten steel flow path after the provision is 102-350 % as large as that before the provision. More preferably, the rate is 105-300 %. Most preferably, the rate is 105-270 %. If the rate is lower than 102 %, the required effect based on the provision of the protrusion portions and/or concave portions  
15 which are characteristic of the invention can be hardly obtained. If the rate is higher than 350 %, the inside of the molten steel flow hole is so narrowed that a sufficient flow rate of molten steel can be hardly kept, undesirably.

          The provision of the protrusion portions and/or concave  
20 portions, which are characteristic of the invention, in the inner hole portion of the nozzle is not particularly limited but it is preferable that the protrusion portions or concave portions are disposed so zigzag as to be displaced in a direction perpendicular to the molten steel flowing direction. That is,  
25 as a preferred embodiment of the casting nozzle according to

the invention, the casting nozzle has a portion in which the protrusion portions and/or concave portions are disposed so zigzag as to be displaced at least in a direction perpendicular to the molten steel flowing direction.

5       The protrusion portions and/or concave portions which are characteristic of the invention can be disposed in the whole or part (e.g. ranging from the upper end portion of the nozzle discharge hole to the center portion of the upper portion) of the molten steel flow hole portion of the nozzle. The positions  
10 where the protrusion portions and/or concave portions are disposed are not limited but it is preferable that the protrusion portions and/or concave portions are disposed so as to be not higher than the meniscus (the surface or liquid level of molten steel in the mold), that is, they are disposed in an immersion  
15 portion.

Preferred positions where the protrusion portions and/or concave portions being characteristic of the invention are disposed will be described below. The present inventors have made a water model experiment by using the immersion nozzles  
20 (A) to (D) shown in Fig. 14. As a measurement item, a flow rate from each discharge hole was measured with a propeller flowmeter 51 by a method (see the later description) shown in Fig. 6. As a result, in (A) of Fig. 14 in which the protrusions 74 were disposed only above the meniscus 72 of the immersion  
25 nozzle 71, a minus flow (suction flow) was observed at two of

flow rate measurement points of the left discharge hole 73. However, in each of (B) to (D) of Fig. 14 in which the protrusions 74 were disposed to be not higher than the meniscus 72, that is, the protrusions 74 were disposed to reach the immersion  
5 portion, there was no minus flow observed. In terms of positions of the protrusions 74 disposed, it is apparent from this fact that the protrusions 74 are preferably disposed so as to be not higher than the meniscus 72, that is, the protrusions 74 are preferably disposed to reach the immersion portion.

10 In the invention, it is preferable that the distance E (see Fig. 8) between bases of the protrusions in a direction (vertical direction) parallel to the molten steel flowing direction is not smaller than 20 mm, that is, even the shortest distance is not smaller than 20 mm. In a range in which the  
15 height H of each protrusion is not larger than 20 mm, there is no stagnation portion generated between the protrusions as long as the distance E between the protrusions in a direction (vertical direction) parallel to the molten steel flowing direction can be kept not smaller than 20 mm. Accordingly,  
20 there is no alumina deposited between the protrusions. The distance E is selected to be preferably not smaller than 25 mm, more preferably not smaller than 30 mm. Incidentally, it is preferable that the height H (see Fig. 8) of each protrusion is selected to be not larger than 20 mm in order to secure  
25 throughput (the amount of passage of molten steel per unit time).

In the invention, it is also preferable that four or more protrusion portions are disposed in the molten steel flow hole portion of the casting nozzle. If the number of protrusion portions is three or less, the effect of straightening molten steel flowing down in the molten steel flow hole portion cannot be expected so that a drift may occur easily.

In the casting nozzle according to the invention, when the protrusion portions each having a height not smaller than 2 mm (preferably, 2 to 20 mm) are disposed, it is preferable that the "angle between the nozzle inner pipe and the lower end portion of each protrusion" in a direction (i.e. a vertical section) parallel to the molten steel flowing direction, that is, the "angle of the lower end of each protrusion portion" is not larger than  $60^{\circ}$ . [The aforementioned "nozzle inner pipe" means the wall surface of an original inner pipe before the provision of the protrusions, and the angle between the wall surface of the inner pipe and the lower end portion of each protrusion is referred to as "angle of the lower end of each protrusion" in this specification.

When illustrated, the "angle of the lower end of each protrusion portion" is, for example, equivalent to " $\theta$ " shown in (D) or (E) of Fig. 9. When the lower portion of each protrusion in a direction (i.e. vertical section) parallel to the molten steel flowing direction is shaped like a circular arc, the "angle of the lower end of each protrusion portion" is set to be an

angle (see " $\theta$ " in Example 16 in Fig. 11) of a line tangential to the circular arc lower end portion. In a range in which the "angle of the lower end of each protrusion portion" is not larger than  $60^\circ$ , there is no stagnation portion generated just under each protrusion portion. Accordingly, there is no alumina deposited just under the protrusion portion. Examples of fluid calculation results are shown in (D) and (E) of Fig. 9. Incidentally, (D) of Fig. 9 shows an example of " $\theta: 45^\circ$ ", and (E) of Fig. 9 shows an example of " $\theta: 70^\circ$ ". If the "angle  $\theta$  of the lower end of each protrusion portion" is larger than  $60^\circ$ , a stagnation portion 43 is generated just under the protrusion portion as shown in (E) of Fig. 9.

Although it is preferable that the "angle  $\theta$  of the lower end of each protrusion portion" is not larger than  $60^\circ$ , the angle  $\theta$  may be allowed to be out of the range if the height  $h$  (the height  $h$  toward the center of the nozzle inner pipe) of the lower end portion is smaller than 2 mm as shown in Example 14 or 15 in Fig. 11. In this case, the angle just above the region may be selected to be not larger than  $60^\circ$ . Incidentally, the "angle  $\theta$  of the lower end of each protrusion portion" is selected to be preferably not larger than  $50^\circ$ , more preferably not larger than  $40^\circ$ , especially preferably not larger than  $30^\circ$ .

The protrusion portions in the invention are preferably molded so as to be integrated with the body of the casing nozzle.

Another method such as fitting than integral molding is not

preferred because there is a possibility that molten steel or steel inclusion will penetrate into a gap between each protrusion portion and the body to cause dropout of the protrusion portion.

Next, an embodiment of the casting nozzle according to the invention will be described with reference to Figs. 4 and 5. Fig. 4 is a sectional perspective view of the immersion nozzle as an embodiment of the invention and shows an example in which a plurality of ellipsoidal protrusion portions 24 are disposed in an inner hole portion (molten steel flow hole portion) 22 of a single-stepped immersion nozzle 20. Fig. 5 is a sectional perspective view of the immersion nozzle as another embodiment of the invention and shows an example in which a plurality of spherical protrusion portions 34 are disposed in an inner hole portion (molten steel flow hole portion) 32 of a straight immersion nozzle 30. Incidentally, in Figs. 4 and 5, the reference numerals 21 and 31 designate body portions; and 23 and 33, powder line portions. Further,  $L_1$  shows the total length of the immersion nozzle,  $L_2$  shows the total length of the inner hole portion,  $L_3$  shows the length of a place where the protrusion portions are disposed,  $L_4$  shows the length of the step,  $h$  shows the height of the step, and  $R$  shows the radius of the inner hole portion.

The conventional method of spraying inert gas may be used together with the aforementioned single-stepped immersion nozzle 20 in which the ellipsoidal protrusion portions 24 are

disposed or with the aforementioned straight immersion nozzle 30 in which the spherical protrusion portions 34 are disposed. Accordingly, an effect of the method of spraying inert gas against alumina deposition can be improved. Use of this method  
5 can be contained in the invention.

Although the example where the invention is applied to a "side hole type" immersion nozzle as shown in Fig. 4 or 5 has been described above chiefly, the invention may be applied to a "bottom hole type" immersion nozzle as shown in (B) of  
10 Fig. 1 or may be applied to an immersion nozzle of a "type with a nozzle inner diameter reduced toward the discharge hole portion" or an immersion nozzle of a "type with a section flattened toward the discharge hole portion". The invention may be further applied to an immersion nozzle having continuous  
15 steps" known heretofore.

The invention may be further applied to various kinds of casting nozzles such as a long nozzle, a tundish nozzle, a semi-immersion nozzle, a straightening nozzle, a change nozzle, a ladle nozzle, an insert nozzle, an injection nozzle, etc.  
20 besides the immersion nozzle. These nozzles are effective in preventing adhesion on the inner surface of the flow hole and straightening a flow in the flow hole. Particularly, in a nozzle having a discharge hole portion located to be higher than the level of molten steel, molten steel out of the discharge hole  
25 is dispersed as if it was sprayed (so-called molten steel

scattering) and, accordingly, the scattered molten steel is deposited as base metal on the peripheral equipment. There is a problem that labor must be required for removing the scattered molten metal. When the invention is applied to these  
5 problems, production efficiency can be improved because the "molten metal scattering" can be reduced as a result of the aforementioned effect.

The material of each of the "protrusion portions and/or concave portions" being characteristic of the invention is not  
10 limited. Any self-evident material can be used in the invention. Examples of the material include: carbon-containing refractory materials such as  $\text{Al}_2\text{O}_3\text{-C}$ ,  $\text{MgO-C}$ ,  $\text{Al}_2\text{O}_3\text{-MgO-C}$ ,  $\text{Al}_2\text{O}_3\text{-SiO}_2\text{-C}$ ,  $\text{CaO-ZrO}_2\text{-C}$ ,  $\text{ZrO}_2\text{-C}$ , etc.; and carbonless refractory materials such as  $\text{Al}_2\text{O}_3$ ,  $\text{MgO}$ , spinel,  $\text{CaO-ZrO}_2$ , etc.

15  
<Examples>

Although the invention will be described below specifically on the basis of Examples of the invention and Comparative Examples, the invention is not limited by the  
20 following Examples 1 to 16.

<Example 1 (see Fig. 4)>

Example 1 is an example in which a plurality of ellipsoidal protrusion portions are disposed in an inner hole portion of  
25 a single-stepped immersion nozzle. The following immersion



nozzle was produced (see Fig. 4 which has been described above) .

- Shape of Immersion Nozzle

5 : single-stepped immersion nozzle with a length  
( $L_4$ ) of 120 mm and a height (h) of 5 mm

: immersion nozzle total length  $L_1 = 800$  mm

: inner hole portion total length  $L_2 = 770$  mm

: inner hole portion radius  $R = 40$  mm

10 • Material of Immersion Nozzle

: body portion 25 wt% of graphite, 50 wt% of  $Al_2O_3$ ,  
25 wt% of  $SiO_2$

: powder line portion 13 wt% of graphite, 87 wt%  
of  $ZrO_2$

15 : inner hole portion 5.5 wt% of carbon, 94.5 wt%  
of  $Al_2O_3$

- Ellipsoidal Protrusion Portions

20 : arrangement position Ellipsoidal protrusion  
portions were disposed in a length of 350 mm ranging upward  
from the upper end portion of the discharge hole. ( $L_3 = 350$   
mm)

: 54 ellipsoidal protrusion portions

: maximum height 8 mm

25 : base portion maximum length 32 mm

: material low carbon material the same as that of the inner hole portion of the immersion nozzle

(The increasing rate of the surface area of the nozzle inner hole portion in the region of arrangement of the ellipsoidal protrusion portions to the "surface area of the nozzle inner hole portion in the region before the arrangement of the ellipsoidal protrusion portions") was 116 %).

<Comparative Example 1>

10 In the aforementioned Example 1, an immersion nozzle having no ellipsoidal protrusion portion arranged was produced. This was made as an immersion nozzle according to Comparative Example 1 (to be compared with Example 1).

(Water Model Experiment)

15 Each of the immersion nozzles according to Example 1 and Comparative Example 1 was used and a water model experiment was performed. In the water model experiment, as shown in Fig. 6, the discharge flow rate from the discharge hole of each immersion nozzle 50 was measured with the propeller flowmeter 20 51. Incidentally, Fig. 6 is a view for explaining discharge flow rate measurement points (1) to (9) in a water model experiment apparatus. In Fig. 6, (A) is a sectional view showing a right lower portion of the apparatus, and (B) is a view showing the shape of an opening in the discharge hole surface x of (A). 25 In the experiment, the amount of water was adjusted so as to

be equivalent to 3 (ton/min), 5 (ton/min) or 7 (ton/min) as the amount of passage of molten steel (throughput) in the immersion nozzle 50. Discharge flow rates from the left and right discharge holes were measured simultaneously with two propeller flowmeters 51. Fig. 7 shows a result of measurement of the discharge flow rates.

As a result of the water model experiment, in the case where the single-stepped immersion nozzle according to Comparative Example 1 was used, a "minus flow (suction flow)" was generated in the discharge flow rate from each of the left and right discharge holes as shown in Fig. 7 when the throughput was 3 (ton/min) or 5 (ton/min). On the contrary, in the immersion nozzle according to Example 1 in which the ellipsoidal protrusion portions were provided in the inner hole portion of the single-stepped immersion nozzle, there was no minus flow generated, and variation in the discharge flow rate was reduced.

If a minus discharge flow rate was generated, there was a risk that mold powder put in the mold would be involved, and there arose a problem that melting loss occurred in the peripheral portion of the discharge hole. In the immersion nozzle according to Example 1, the generation of such a minus flow was eliminated. In the single-stepped immersion nozzle according to Comparative Example 1, the difference between the discharge flow rates from the left and right discharge holes was large. On the other hand, in the immersion nozzle according

to Example 1, the difference was reduced so that a more uniform discharge flow could be obtained.

<Example 2 (see Fig. 5)>

5           Example 2 is an example in which a plurality of spherical (globular) protrusion portions are disposed in an inner hole portion of a straight immersion nozzle. The following immersion nozzle was produced (see Fig. 5 which has been described above).

10           • Shape of Immersion Nozzle

- : immersion nozzle having a straight inner pipe
- : immersion nozzle total length  $L_1 = 900$  mm
- : inner hole portion total length  $L_2 = 870$  mm
- 15           : inner hole portion radius  $R = 45$  mm

            • Material of Immersion Nozzle

- : body portion 25 wt% of graphite, 50 wt% of  $Al_2O_3$ ,  
25 wt% of  $SiO_2$
- 20           : powder line portion 13 wt% of graphite, 87 wt%  
of  $ZrO_2$

            • Spherical (Globular) Protrusion Portions

- : arrangement position Spherical protrusion
- 25           portions were disposed in a length of 450 mm ranging upward

from the upper end portion of the discharge hole. ( $L_3 = 450$  mm)

: 70 spherical protrusion portions

: maximum height 10 mm

5 : base portion maximum length 27 mm

: material the same as that of the body portion of the immersion nozzle

(The increasing rate of the surface area of the nozzle inner hole portion in the region of arrangement of the spherical protrusion portions to the "surface area of the nozzle inner hole portion in the region before the arrangement of the spherical protrusion portions") was 114 %).

#### <Comparative Example 2>

15 In the aforementioned Example 2, an immersion nozzle having no spherical (globular) protrusion portion arranged was produced. This was made as an immersion nozzle according to Comparative Example 2 (to be compared with Example 2).

(Water Model Experiment)

20 Each of the immersion nozzles according to Example 2 and Comparative Example 2 was used and a water model experiment was performed in the same manner as in each of the immersion nozzles according to Example 1 and Comparative Example 1. The result was the same as the result of the water model experiment  
25 for the immersion nozzles according to Example 1 and Comparative

Example 1.

The immersion nozzles according to Examples 1 and 2 were subjected to a practical test on the basis of the result of the water model experiment for Examples 1 and 2. As a result, molten steel was restrained from drifting in the mold, and alumina was prevented from being deposited on the nozzle inner hole portion. The effectiveness of the immersion nozzles according to Examples 1 and 2 was confirmed.

10 <Examples 3 to 8 and Comparative Examples 3 to 8 (see Figs. 2 and 3)>

Besides Examples 1 and 2 and Comparative Examples 1 and 2, examples (Examples 3 to 8 and Comparative Examples 3 to 8) were examined. The examples inclusive of Examples 1 and 2 and Comparative Examples 1 and 2 were tabled as a list and shown in Fig. 2 (Examples) and Fig. 3 (Comparative Examples). Incidentally, the shape and material of each of the nozzles according to Examples 3 to 8 and Comparative Examples 3 to 8 were made equal to those of Example 2 except the diameter (D) of the nozzle inner hole portion.

In Figs. 2 and 3, " $L/H$ " and " $\pi D/L$ " are shown. If the value of " $L/H$ " is a "value larger than 2 ( $2<$ )", the "expression (2):  $L > 2 \times H$ " is satisfied. If the value of " $\pi D/L$ " is a "value not smaller than 3 ( $3\leq$ )", the "expression (3):  $L \leq \pi D/3$ " is satisfied. In Figs. 2 and 3, the shape of each protrusion is

shown as "approximate shape". (Because it is difficult to draw a "spherical" shape and an "elliptic" shape distinctively, the two shapes are shown as the same shape except the spherical protrusions in Comparative Example 3).

5           In Figs. 2 and 3, "surface area increasing rate (%)" means the increasing rate of the "surface area of the nozzle inner hole portion after arrangement of the protrusions" to the "surface area of the nozzle inner hole portion before arrangement of the protrusions". Specifically, it means the surface area  
10   increasing rate in a region ranging from the start point of the protrusions in the uppermost portion (fitting portion side) to the end point of the protrusions in the lowermost portion (bottom portion).

          The "degree of drifting" is evaluated in such a manner  
15   that a flow of discharged water is observed in the condition that 10 L/min of air is blown from the upper nozzle (tundish upper nozzle) in the water model experiment to make it easy to check the flow of discharged water. For example, in the case of Comparative Example 2, the "degree of drifting" is  
20   "large". This shows a state in which the meniscus (near the water level) near the right short side of the mold is swollen by an inverted current (upwelling current) generated because the left discharge flow is discharged downward at an angle of about 45° and creeps deeply to the lower end of the mold whereas  
25   the right discharge flow is discharged downward at an angle

of about  $10^\circ$  and collides with the short side of the mold vigorously. That is, the state in which the left and right discharge flows are not uniform is referred to as "drifting". The "drifting" in accordance with the difference between the  
5 left and right discharge flows is simply shown in the list.

In Figs. 2 and 3, "strength of protrusion" is evaluated in such a manner that a state of each protrusion is checked after the immersion nozzle used in the actual machine is collected and cut. "OK" expresses the fact that there is no  
10 damage (dropout) of each protrusion based on the collision with the molten steel flow. "NG" expresses the fact that damage of at least part of the protrusion is found. "Deposition of Alumina on Inner Pipe" is a result of measurement of the maximum thickness of alumina deposited after the nozzle used in the  
15 actual machine is collected. Generally, when the thickness of alumina is smaller than about 3 mm, there is no operating problem. If the thickness of alumina is larger than 5 mm, there arises a problem that throughput (the amount of molten steel passing through the pipe per predetermined time) cannot be kept  
20 or cast piece quality deteriorates because single-flow occurs in accordance with the state of deposition.

In Figs. 2 and 3, "total evaluation" is made as follows. The case where there is no problem at all in "drifting" and "minus flow" in the water model experiment and in "strength  
25 of protrusion" in use of the actual machine is evaluated as



"◎" if the "amount of alumina deposited on the inner pipe" is not larger than 1 mm, and as "○" if the "amount of alumina deposited on the inner pipe" is about 3 mm. The nozzle evaluated as "◎" or "○" exhibits an excellent effect compared with the conventional nozzle. The nozzle evaluated as "×" has a problem in any one of "drifting" and "minus flow" in the water model experiment and "strength of protrusion" in use of the actual machine. For this reason, the nozzle evaluated as "×" results in the "amount of alumina deposited on the inner pipe" being not smaller than 5 mm. Particularly in Comparative Examples 3 and 4, though there is no problem in evaluation in the water model experiment, the protrusions drop out in use of the actual machine to cause a state as if the protrusion were not disposed. As a result, a large amount of alumina is deposited.

[Incidentally, as an annotation, only the convex portion of a step disposed on the straight inner pipe is drawn in the approximate shape of Comparative Example 1. In this case, the "maximum length (L) of the base portion" means the length of the outer circumference of this drawing, that is, the length is equal to the "length of the inner circumference of the inner pipe" which is originally straight].

<Example 9 and Comparative Examples 9 and 10 (see Fig. 8):  
Experimental Example using Acrylic Immersion Nozzle>

Example 9 and Comparative Examples 9 and 10 to be compared

with Example 9 will be described with reference to Fig. 8. Incidentally, Fig. 8 is a view vertically cut in a direction parallel to the molten steel flowing direction.

5        Elliptic protrusion portions 82 each having a height  $H = 10$  mm and a maximum base portion length  $L_5 = 30$  mm in a direction (horizontal direction) perpendicular to the molten steel flowing direction were disposed in an acrylic immersion nozzle 81 with an inner diameter  $\phi$  of 80 mm. A water model experiment was performed.

10        In Example 9, the distance  $E$  between protrusion portions and base portions of the protrusion portions in a direction (vertical direction) parallel to the molten steel flowing direction was set at 20 mm. On the other hand, in Comparative Example 9, a straight nozzle having no protrusion portion 82  
15        disposed was used. In Comparative Example 10, a nozzle having protrusion portions (elliptic protrusion portions 82 of  $H = 10$  mm and  $L = 30$  mm like Example 9) disposed at intervals of the distance  $E = 10$  mm (out of the range specified by the invention) was used.

20        A flow of water in the inner hole portion was checked by eye observation in the condition of throughput equivalent to 5 steel  $\cdot$  T/min. As a result, in Example 9, water flowed just under the protrusion portions and it was confirmed that there was no stagnation portion. In Comparative Example 10, water  
25        did not flow just under the protrusion portions and there were

stagnation portions.

Then, maximum throughputs of Example 9 and Comparative Examples 9 and 10 were measured. A slide valve attached to the upper portion of the immersion nozzle was opened fully and  
5 a flow rate adjusting valve near a pump for circulating water was adjusted so that the water level in the mold was stabilized to a predetermined height (250 mm upward from the upper end of the discharge hole). The flow rate in this case was measured with a float type flowmeter. As a result, in the straight nozzle  
10 according to Comparative Example 9, water flowed up to the maximum throughput: 1200 L/min. On the other hand, in Comparative Example 10, water flowed up to only 850 L/min. On the contrary, in Example 9, water flowed up to 1150 L/min and the influence of the provision of the protrusion portions was  
15 slightly observed but the influence was suppressed to such a degree that there was no influence on the operation of the actual machine. This is conceived that water flows just under the protrusion portions in Example 9 to make it possible to keep throughput because the necessary distance of  $H = 20$  mm is kept,  
20 whereas water does not flow just under the protrusion portions in Comparative Example 10 to cause the same state as if the diameter of the inner hole per se were totally reduced because of only  $H = 10$  mm. Incidentally, it is conceived that if fluid does not flow just under each protrusion portion as shown in  
25 Comparative Example 10, the portion just under the protrusion

portion serves as a stagnation portion on which alumina will be deposited in the actual machine.

<Example 10 and Comparative Examples 11 and 12 (see Fig. 9):

5    Experimental Example using Acrylic Immersion Nozzle>

Example 10 and Comparative Examples 11 and 12 will be described with reference to (A) to (E) of Fig. 9. Incidentally, (A) of Fig. 9 is a view showing an immersion nozzle according to Example 10, and (B) and (C) of Fig. 9 are views showing immersion  
10    nozzles according to Comparative Examples 11 and 12 respectively. Each of these is a view vertically cut in a direction parallel to the molten steel flowing direction. Further, (D) of Fig. 9 is a view showing a section of a protrusion portion taken in a direction parallel to the molten steel flowing direction  
15    in the immersion nozzle (Example 10) depicted in (A) of Fig. 9, and (E) of Fig. 9 is a view showing a section of a protrusion portion taken in a direction parallel to the molten steel flowing direction in the immersion nozzle (Comparative Example 12) depicted in (C) of Fig. 9. These are views for explaining results  
20    of the "water model experiment" of the immersion nozzles according to Example 10 and Comparative Example 12.

Example 10 will be described with reference to (A) and (D) of Fig. 9. Example 10 is an example in which protrusion portions 41a each having a height of  $H = 10$  mm and a protrusion  
25    lower end angle of  $\theta = 45^\circ$  are disposed in a transparent acrylic

immersion nozzle 40a having an inner diameter  $\phi$  of 80 mm. As shown in (B) of Fig. 9, Comparative Example 11 uses an immersion nozzle (straight nozzle) 40b having no protrusion portion disposed. As shown in (C) of Fig. 9, Comparative Example 12 uses an immersion nozzle 40c in which protrusion portions 41c each having a height of  $H = 10$  mm and a protrusion lower end angle of  $\theta = 70^\circ$  are disposed. Incidentally, the protrusion portions 41a in Example 10 or the protrusion portions 41c in Comparative Example 12 were not annularly continuous so that four protrusion portions 41a or 41c were disposed on a plane perpendicular to the molten steel flowing direction and three stages of protrusion portions 41a or 41c were disposed in a direction parallel to the molten steel flowing direction, that is, twelve protrusion portions 41a or 41c in total were disposed.

#### (Water Model Experiment)

Each of the immersion nozzles according to Example 10 and Comparative Examples 11 and 12 was subjected to a "water model experiment". First, a flow of water in the inner hole portion was checked by eye observation in the condition of throughput equivalent to 5 steel·T/min. As a result, in the immersion nozzle 40a according to Example 10, water flowed even just under each protrusion 41a, so that it was confirmed that there was no stagnation portion [see "water flow 42a" in (D) of Fig. 9]. On the contrary, in the immersion nozzle 40c according to Comparative Example 12, water did not flow smoothly

just under each protrusion portion 41c, so that there were stagnation portions 43 [see "water flow 42b" in (E) of Fig. 9].

Then, maximum throughputs of the immersion nozzles according to Example 10 and Comparative Examples 11 and 12 were measured. A slide valve attached to the upper portion of the immersion nozzle was opened fully and a flow rate adjusting valve near a pump for circulating water was adjusted so that the water level in the mold was stabilized to a predetermined height (250 mm upward from the upper end of the discharge hole). The flow rate in this case was measured with a float type flowmeter. As a result of measurement, in the immersion nozzle (straight nozzle) 40b according to Comparative Example 11, water flowed up to the maximum throughput: 1200 L/min. On the other hand, in the immersion nozzle 40c according to Comparative Example 12, water flowed up to only 1080 L/min. On the contrary, in the immersion nozzle 40a according to Example 10, water flowed up to 1170 L/min and the influence of the provision of the protrusion portions 41a was slightly observed but the influence could be suppressed to such a degree that there was no influence on the operation of the actual machine. This is conceived that water flows just under the protrusion portions 41a in Example 10 to make it possible to keep throughput because the necessary protrusion lower end angle of  $45^\circ$  is kept, whereas water does not flow just under the protrusion portions 41c in Comparative

Example 12 to cause the same state as if the diameter of the inner hole per se were totally reduced because of the large protrusion lower end angle  $\theta$  of  $70^\circ$ . It is experimentally proved that if fluid does not smoothly flow just under each protrusion portion as shown in Comparative Example 12, the portion just under the protrusion portion serves as a stagnation portion on which alumina will be deposited in the actual machine.

<Example 11 and Comparative Example 13 (see Fig. 10):

10 Experimental Example using Acrylic Immersion Nozzle>

Example 11 and Comparative Example 13 will be described with reference to (A) to (D) of Fig. 10. Incidentally, (A) of Fig. 10 is a view showing an immersion nozzle according to Example 11, and (B) of Fig. 10 is a view showing an immersion nozzle according to Comparative Example 13. Each of these is a view vertically cut in a direction parallel to the molten steel flowing direction. Further, (C) of Fig. 10 is a schematic view for explaining a discharge flow in the immersion nozzle (Example 11) depicted in (A) of Fig. 10, and (D) of Fig. 10 is a schematic view for explaining a discharge flow in the immersion nozzle (Comparative Example 13) depicted in (B) of Fig. 10.

As shown in (A) of Fig. 10, Example 11 is an example in which protrusion portions 91a each having a height of 13 mm and a protrusion lower end angle of  $35^\circ$  are disposed in a

transparent acrylic immersion nozzle 90a having an inner diameter  $\phi$  of 70 mm. As the protrusion portions 91a, four stages of protrusion portions, that is, sixteen protrusion portions in total are disposed so that four protrusion portions are  
5 disposed on a plane perpendicular to the molten steel flowing direction. On the other hand, as shown in (B) of Fig. 10, Comparative Example 13 uses an immersion nozzle 90b in which protrusion portions 91b each having the same vertical sectional shape as that in Example 11 but annularly continuous on a plane  
10 perpendicular to the molten steel flowing direction are disposed as four stages of protrusion portions.

(Water Model Experiment)

Each of the immersion nozzles according to Example 11 and Comparative Example 13 was subjected to a "water model  
15 experiment". The water model experiment was performed in the condition that throughput was set to be equivalent to 4 steel  $\cdot$  T/min in such a manner that three slide plates 93 were used and middle one of the three slide plates 93 was slid in parallel to a long side of a mold 94 to control the flow rate  
20 as shown in (C) and (D) of Fig. 10. Further, 5 L/min of air was blown from the upper nozzle 92 disposed just on the slide plates 93 so that a flow of water 96 in the mold 94 could be observed easily.

A result of Example 11 is shown in (C) of Fig. 10, and  
25 a result of Comparative Example 13 is shown in (D) of Fig. 10.



Flows of water discharged from the discharge holes and flowing in the molds 94, that is, discharge flows 95a and 95b are illustrated in brief. In the immersion nozzle 90a according to Example 11 in which the protrusion portions were independent of each other, the flow of water [discharge flow 95a] in the mold 94 was substantially uniform and stable bisymmetrically. On the contrary, in the immersion nozzle 90b according to Comparative Example 13 in which each of the protrusion portions was shaped like a ring, the right discharge flow 96b crept more deeply than the left discharge flow, that is, it was apparent that drifting could not be eliminated. Accordingly, it is proved that independent protrusions are preferred to ring-like protrusions each being annularly continuous on one plane perpendicular to the molten steel flowing direction.

<Examples 12 to 16 and Comparative Examples 14 to 18 (see Fig. 11): Experimental Example using Acrylic Immersion Nozzle>

Fig. 11 shows "sectional shapes of protrusion portions (sectional shapes cut in parallel to the molten steel flowing direction)" disposed in immersion nozzles according to Examples 12 to 16 and Comparative Examples 14 to 18. Among these, each of the protrusion portions in Examples 14 and 15 is shown as an example in which the height (height  $h$  toward the center of the nozzle inner pipe) of the lower end portion of each protrusion portion was set at 1 mm. Incidentally, each of the immersion

nozzles according to Examples 12 to 16 and Comparative Examples 14 to 18 is a transparent acrylic immersion nozzle having an inner diameter  $\phi$  of 80 mm and having protrusion portions with a maximum height of 8 mm.

5 (Water Model Experiment)

Each of the immersion nozzles according to Examples 12 to 16 and Comparative Examples 14 to 18 was subjected to a "water model experiment". Fig. 11 shows results of the experiment. As was apparent from Fig. 11, in each of the immersion nozzles according to Examples 12, 13 and 16 in which the "protrusion lower end angle  $\theta$ " was "not larger than  $60^\circ$ ", stagnation was not observed just under each protrusion portion and a good straightening effect was obtained. Even in each of Examples 14 and 15 in which the height (height  $h$  toward the center of the nozzle inner pipe) of the lower end portion of each protrusion portion was set at "1 mm", it was found that stagnation was not observed just under each protrusion portion and a good straightening effect was obtained if the height was smaller than 2 mm and the "protrusion lower end angle  $\theta$ " was "not larger than  $60^\circ$ ".

On the contrary, in each of the immersion nozzles according to Comparative Examples 14 to 18 in which the "protrusion lower end angle  $\theta$ " was "not smaller than  $60^\circ$ ", stagnation was observed just under each protrusion portion and there was no good straightening effect obtained.

### <Industrial Applicability>

Use of the casting nozzle according to the invention permits (1) elimination of drifting in the molten steel flow hole portion of the nozzle, (2) uniformization of the flow rate distribution in the discharge hole portion (to prevent generation of minus flow) to prevent melting loss in the discharge hole portion due to suction of mold powder, (3) elimination of drifting in the left and right of the mold and (4) prevention of deposition of alumina on a space between protrusions to continue the effect of the protrusions disposed in the molten steel flow hole portion of the nozzle. As a result, continuous casting of steel can be performed easily. In addition, high-quality steel can be cast easily because mold powder is not involved.